3239

HPGe CORE COUNTER CALIBRATION REPORT

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
FERNALD, OHIO

SEPTEMBER 2000

U.S. DEPARTMENT OF ENERGY
FERNALD AREA OFFICE

20310-RP-0005
REVISION A
DRAFT

3239

OVERVIEW

This report describes the testing and analysis performed by Fluor Fernald personnel in the Real Time Instrumentation Measurements Program (RTIMP) to develop a new tool, the Core Counter, that can be used by environmental engineers during the remediation of the Fernald Environmental Management Project (FEMP). The Core Counter is a special configuration lead shield and gamma spectrometry system capable of measuring total uranium concentrations of soil in cylindrical core liners. It was developed as a screening tool to provide uranium analyses of core samples so that environmental engineers do not have to demobilize personnel and equipment while waiting for laboratory analysis results to determine if additional core sampling is necessary. At the present time, the Core Counter is calibrated only for uranium.

Sections 1 through 4 of this report describe the preparation of calibration standards and the measurements and analyses performed to derive Core Counter calibration equations. Two different diameter tubes are typically used to collect core samples on the FEMP site. A separate linear calibration equation was derived for each diameter core tube. With these calibration equations, a result that is equivalent to a laboratory analysis can be quickly calculated from raw Core Counter data. Using data from the calibration standards, statistically based trigger levels were developed to provide a margin of conservatism in consideration of normal measurement uncertainty. Core Counter readings in excess of the trigger levels will be considered to indicate above waste acceptance criteria (WAC) soil, even though the equivalent laboratory results may be slightly below WAC.

Sections 5 through 9 of the report describe the "bench scale" testing that was performed to verify that the calibrations provide accurate results and yield proper decisions about whether or not the soil cores contain uranium above WAC for the On-Site Disposal Facility.

The data presented in the report demonstrate that, in most instances, the Core Counter does result in proper WAC decisions. Evidence is presented that shows that core segments with high uranium activity can interfere with the counts of nearby core segments, and that false positive error rates on WAC decisions become significant above 800 parts per million total uranium concentration. However, both of these circumstances lead to conservative WAC decisions.

2

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

EGAS	Environmental Gamma Analysis Software®
FEMP	Fernald Environmental Management Project
FRL	final remediation level
g/cm^3	grams per cubic centimeter
HPGe	high purity germanium (detector)
Kev	kilo-electron volts
OSDF	On-Site Disposal Facility
ppm	parts per million
RTIMP	Real Time Instrumentation Measurements Program
WAC	waste acceptance criteria

1.0 INTRODUCTION

3239

This report documents the calibration, bench scale testing, and recommendations for field usage of the real-time high purity germanium (HPGe) Core Counter. The Core Counter is designed to provide rapid analysis of total uranium concentrations in field Geoprobe® borings, which will indicate whether additional borings are needed to bound soil contamination. This will eliminate having to demobilize, wait for laboratory analysis, and remobilize field personnel and equipment to acquire additional borings. The Core Counter will facilitate prompt decision making during predesign investigations when soil contamination is identified, as well as during excavations when contaminated soil is being removed.

The Core Counter consists of an HPGe detector inserted into a lead shield, or "cave," consisting of lead bricks stacked in a fixed configuration. A schematic diagram of the Core Counter is shown in Figure 1. This design allows a Geoprobe® liner of any length to be inserted into openings in the sidewalls of the cave and positioned immediately in front of the detector. Because of the interior width of the shield cavity, the detector measures the activity of 6-inch soil segments. Each segment is counted to determine the total uranium concentration within that 6-inch increment. Normally the laboratory receives 6-inch core segments for analysis. Currently at the Fernald Environmental Management Project (FEMP), there are two gamma spectral analysis software packages available for use: EGAS (i.e., Environmental Gamma-Ray Analysis Software) and GammaVision™. Detailed comparisons by Real Time Instrumentation Measurements Program (RTIMP) personnel have shown that these two software packages produce very comparable results. While EGAS was used for the work described in this report, GammaVision™ could just as well be used for routine applications of the Core Counter since it generates equivalent results. The critical step in obtaining Core Counter results equivalent to those that a laboratory would generate occurs after the spectral analysis software has generated total uranium ppm values.

The Core Counter was originally developed to determine total uranium concentration in the soil at or near the On-Site Disposal Facility (OSDF) waste acceptance criteria (WAC) level of 1,030 parts per million (ppm). Bench scale testing indicates the potential for total uranium "hot spot" identification (3xFRL) with the current calibration equations; additional development will be needed to determine whether the instrument can reliably detect final remediation levels (FRLs).

2.0 HPGe CORE COUNTER CALIBRATION

3239

Using the Core Counter requires a calibration curve to convert the number of gamma rays detected by the counter from the uranium-contaminated soil in the core segment into total uranium concentration. These results must be comparable to laboratory analyses in order to render the same characterization decision (i.e., whether soil is above or below WAC).

Developing the calibration for the Core Counter presented several challenges:

- To date, analysis of soil by *in situ* techniques has involved relatively large-area, flat surfaces; the challenge was to obtain consistently reliable analyses from smaller samples which did not have flat surfaces. For example, the Geoprobe® liner inserted into the cave is a small-diameter cylinder; consequently, the normal *in situ* calibration would not provide accurate results. A geometric correction to allow the detectors that were calibrated for a flat surface to be useable for this cylindrical geometry would have to be developed.

- Gamma spectrum analysis software also assumes a flat, planar volume of gamma-emitting material is being measured. The Environmental Gamma Analysis Software® (EGAS) package, which is the same gamma analysis software currently in use for routine *in situ* HPGe field counting, was tested to determine if it could accommodate the cylindrical geometry. While the program was not designed for this geometry, the concentrations reported by the software would vary linearly with the actual uranium concentration in the soil core samples.

- Early bench scale testing showed that the initial EGAS readout had to be "blank corrected" prior to applying the calibration algorithm in order to obtain accurate "laboratory equivalent" total uranium results from the Core Counter (i.e., total uranium concentrations comparable to laboratory analyses). The blank is a 6-inch segment of Geoprobe® liner filled with soil determined to contain natural background levels of uranium and other gamma emitters.

Once these challenges were understood and overcome, the results of both analysis methods (laboratory and Core Counter) could be compared and linear regression methods could be used to determine the calibration algorithm.

6

3.0 CALIBRATION STANDARDS PREPARATION

3239

The gamma spectrometry systems employed in the Core Counter are the standard systems used by the RTIMP for *in situ* soil measurements. The HPGe detectors that are the heart of these systems were calibrated in a manner that will yield accurate radionuclide concentrations when measurements are performed over a planar surface of a uniformly contaminated large area slab of soil of 4 to 6 inches thickness. The geometry encountered when counting soil cores is radically different from the normal *in situ* geometry. Consequently, to obtain accurate total uranium concentrations when counting soil cores in the Core Counter, it was necessary to correlate Core Counter readouts, which were based on an assumed planar geometry, with accurate total uranium laboratory analyses. This correlation will be referred to as the "calibration curve." Before such a calibration curve could be derived, it was necessary to make soil core standards of known uranium concentration and count them with the Core Counter. Linear regression techniques were then used to derive a calibration curve to correlate the two analyses. To produce standards for the Core Counter, the following steps were performed for FEMP soil samples of varying total uranium concentrations:

1. Samples were retrieved from archival storage

2. Samples were dried, homogenized and analyzed in the site Analytical Laboratory using gamma spectrometry

3. Samples were transferred into 9-inch long Geoprobe® liners (two different diameters)

4. Samples were counted with the Core Counter, using the EGAS gamma spectrometry software.

Although the standards produced were 9 inches long, the detector could only "see" the center 6 inches of each standard because of the width of the shield cavity. A total of twelve soil core standards were made, six using the dual tube sized Geoprobe® polypropylene liner and six using the macro core sized Geoprobe® liner. All standards were capped on both ends with plastic end caps. The two types of liners varied only in terms of tube diameter. The dual tube liner has a 1.25-inch inside diameter, designed to fit inside the macro core liner with a 1.625-inch inside diameter. Both liners have a wall thickness of 1/16 inch. During Geoprobe® drilling operations, the macro core was usually employed to collect soil in shallow holes. To collect soil in deeper holes where soil boring slumping may occur, or where perched ground water is anticipated, the hole was lined with the macro core liner and the sample material collected in the inner dual tube liner.

The densities of the soil core standards varied from 1.1 grams per cubic centimeter (g/cm^3) to 1.68 g/cm^3, comparable to natural soil densities. The process of obtaining core samples may effect the density of the material packed within the core, and thus there may be considerable variation in density from one soil core to the next. For the 63 kilo-electron volts (Kev) and 93 Kev gamma lines used to quantify uranium, density variations from core to core could impact the accuracy of Core Counter results. However, the impact on the higher energy gamma line at 1001 Kev is likely to be small.

The results of the laboratory gamma spectrometry total uranium analyses are displayed in Tables 1 and 2 for the dual tube and macro tube core standards respectively. Each sample was analyzed in triplicate. In addition to the individual laboratory gamma spectrometry results, Tables 1 and 2 contain the mean and the standard deviation of the three lab analyses. Corresponding Core Counter results are also displayed in Tables 1 and 2. These will be discussed in the following section.

9

4.0 CALIBRATION MEASUREMENTS

3239

As part of the calibration process, Core Counter measurements of the standards described in the previous section of this report were performed on two separate days. On each day, two calibrated HPGe detectors were prepared for daily operations using normal RTIMP operating procedures. Daily detector performance checks consist of an energy calibration and an efficiency and resolution check. Two identical lead caves were constructed from lead bricks. The arrangement of the detector, the shield and a core sample are shown in Figure 1. All twelve standards (six dual tube and six macro core standards) were counted in each cave. In this manner, a total of four counts were performed on each of the 12 standards over two days. This repeat counting was performed to account for changing environmental conditions and for variability introduced when positioning detectors and samples in the caves.

Once the gamma emission spectra were obtained, the EGAS spectrum analysis software was used to determine the total uranium concentrations of the core standards. For normal *in situ* measurements, reported radionuclide concentrations are based on the gamma flux from roughly ten million cubic centimeters of soil assumed to be in a "planar slab" geometry. However, in the Core Counter configuration, the detector records the flux from 200 cubic centimeters or less of soil. Thus, even though some of the core samples were known to contain uranium concentrations above WAC, it was expected that EGAS would report low uranium concentrations because of the small sample size. The samples were closer to the detector, which counteracted the effect of the small sample size to some extent, but the reduced separation could not completely overcome the vast difference in sample size. While the laboratory analysis results varied from near background levels of uranium to 1,400 ppm, the raw EGAS output for the core standards varied from background to only 54 ppm. The ratio of lowest to highest EGAS results is ten times smaller than the corresponding ratio for the lab results for the core standards. In effect, the reduced gamma flux from the much smaller core sample makes it important to "blank correct" the raw EGAS core counter output before applying the calibration algorithm. Because the blank constitutes a higher percentage of the EGAS output, blank subtraction is necessary to obtain accurate results.

Applying the reasoning above, the data reduction process for the Core Counter calibration standards was as follows. The total uranium concentration reported by EGAS for the "blank" was subtracted from the reported concentration of each core standard. The resultant values were averaged and a linear regression performed to derive an equation relating blank corrected core counter results to laboratory gamma spectrometry results. Both uncorrected and blank corrected individual Core Counter measurement results are displayed in Tables 1 and 2. Average values and standard deviations of the blank corrected measurements are also presented in these tables.

Figure 2 shows the blank corrected Core Counter results for the dual tube core standards plotted on the x-axis, with corresponding laboratory results plotted on the y-axis. One-sigma error bars for both Core Counter and lab results are also plotted on the graph along with each x-y pair. The central solid diagonal line in this figure represents the "calibration curve" which resulted from the regression analysis. The linear regression equation which represents this line is:

$$y = 44.351x + 0.3408$$

where x = the blank corrected and moisture corrected Core Counter result from a dual tube core sample, and

y = the equivalent result that would be derived from lab gamma spectrometry analysis.

This is the "calibration equation" that will be used to convert blank corrected Core Counter results to equivalent laboratory results. As explained in the next section of this report, these are laboratory-equivalent dry weight results. For example, if a count of a dual tube sample resulted in a blank corrected readout of 15 ppm total uranium, and the soil in the sample was known to contain 10 percent moisture on a dry weight basis, the moisture corrected Core Counter reading would be (15 ppm * 1.1) = 16.5 ppm, and the equivalent laboratory gamma spectrometry total uranium result would be 732.1 ppm (dry weight basis).

The upper and lower prediction limits (95 percent confidence) are also shown on the graph in Figure 2 as lighter solid lines above and below the heavier central calibration curve. The upper prediction limit can be used to estimate (or predict), with 95 percent confidence, the largest y-value (lab total uranium result) which is likely to be derived from a single measured x-value (Core Counter blank corrected total uranium). The upper prediction limit is larger than the usual confidence limits that would be calculated based upon repeated determinations of Core Counter total uranium using the same sample. The value of the upper prediction limit is that it may be used to establish a Core Counter total uranium trigger level, which when exceeded, indicates that lab total uranium results would exceed 1,030 ppm with 95 percent confidence. As Figure 2 indicates, when a blank corrected Core Counter result for a dual tube sample equals 19.2 ppm on a dry weight basis, the upper limit for a single laboratory gamma analysis of this soil would be 1,030 ppm. This number represents a Core Counter value which, if exceeded, identifies soil containing uranium above OSDF WAC. One may say with 95 percent confidence that Core Counter results below the trigger level do not exceed WAC. The data used to calculate the upper prediction limits and the corresponding WAC trigger levels are displayed in Table 1.

3239

Table 2 and Figure 3 contain the corresponding information for the macro core standards. The calibration equation which results from linear regression of blank corrected Core Counter analyses of macro core tube standards on laboratory gamma spectrometry analyses is:

$$y = 27.835x - 1.7284$$

where x = the blank corrected and moisture corrected Core Counter result from a macro core sample, and

y = the equivalent result that would be derived from lab gamma spectrometry analysis.

Using the data in Table 2, the trigger level for macro core samples in the Core Counter was calculated to be 30.6 ppm on a dry weight basis.

The statistical parameters associated with the linear regressions used to derive both the dual tube and macro core calibration equations are presented in Table 3. The "R square" parameter, the square of the correlation coefficient, indicates how well the experimental data points are represented by the linear regression equation. The value of R^2 is greater than 0.99 for both sized core tubes, which indicates an excellent fit to the data. It will be noted that zero is included in the 95 percent confidence interval for the intercept in both calibration equations. In other words, with 95 percent confidence, the intercept in each calibration equation is not significantly different from zero. So the intercept term in each of the calibration equations could just as well be eliminated. However, since the intercepts were so small, it would make little practical difference if the regressions were repeated to derive calibration equations with no intercept terms. The labor involved in repeating the regression analyses and recalculating the prediction limits and trigger levels would not be justified by the small changes that would result.

5.0 MOISTURE CORRECTIONS

3239

Regulatory limits for uranium in soil are stated on a dry weight basis. Consequently, total uranium concentrations must be reported on a dry weight basis. This method of reporting eliminates variability in measurement results arising from normal fluctuations in soil moisture and compensates for the shielding effect that water has on gamma rays emitted from soil particles. When deployed in the field, the Core Counter will be receiving cores directly from the ground, which will contain moisture. The measurement data will require a moisture correction to be applied to derive the total uranium concentration expressed on a dry weight basis.

Since the soil core standards used to determine the algorithm had been dried in the laboratory (as part of the laboratory gamma analysis) prior to counting by the Core Counter, the resultant calibration algorithm is inherently the correlation between dry weight measurement results from the Core Counter and dry weight laboratory results. When the Core Counter is deployed in the field, a moisture correction must be applied after the Core Counter reading has been blank corrected and before the calibration equation is applied. Moisture measurements of the soil in a sealed Geoprobe® liner are not possible in the field using current moisture measurement equipment; therefore, either a default moisture value for subsurface soil will have to be applied, or moisture measurements will have to be performed after the cores are cut open. If a default moisture value is applied, it will be done in accordance with the guidelines provided in the report "User Guidelines, Measurement Strategies, and Operational Factors for Deployment of In Situ Gamma Spectrometry at the Fernald Site," also known as the User's Manual. Section 3.8 of this manual lists a default moisture value of 20 percent to be used when moisture measurements cannot be obtained. It may be argued that typical moisture levels at depths below three feet are less than 20 percent because rainfall doesn't generally penetrate the soil to such depths. (Soil moistures encountered in the two cores obtained for the bench scale test ranged from a low of 6.4 percent to a high of 18.9 percent.) However, at the present time, there is minimal data available to derive a more representative value. It can be said that such a high default moisture value will be realistic when perched water or groundwater aquifers are encountered, and, under more normal subsurface soil conditions, it will be conservatively high. The experience gained from operation of the Core Counter over time will permit the construction of a database that could be used to revise the default moisture value for soil at depth.

6.0 CALIBRATION VERIFICATION - BENCH SCALE TEST

3239

To verify the calibration just derived, a bench scale test was performed. Two 4-foot long, dual tube Geoprobe® core liners were used to collect soil for analyses with the Core Counter. One core contained approximately 36 inches of soil; the other, approximately 42 inches. The cores came from FEMP former production area near Plant 6. This location was chosen because an earlier sampling event showed there was total uranium in excess of WAC levels in the soil adjacent to Plant 6. Once collected, the sample soil cores were frisked on the outside and found to exhibit a wide range of direct radiation measurements, indicating the potential for a wide range of total uranium concentrations. The sample soil cores were counted using the Core Counter on four different days using a different HPGe instrument each day.

After all the Core Counter measurements were completed, the site sampling organization, complying with chain-of-custody requirements and using existing site sampling procedures, cut the two cores into 6-inch intervals. Core 1 yielded six soil segments, while Core 2 yielded seven segments. The samples were submitted for laboratory gamma spectroscopy analysis. Care was taken to ensure that the intervals analyzed by the laboratory matched exactly the intervals measured by the Core Counter. The laboratory analysis results are displayed in Tables 4A and 4B along with the four Core Counter measurement results for the individual core segments. These tables show the initial core Counter outputs (wet weight total uranium results), intermediate dry weight total uranium values, and the "laboratory equivalent" Core Counter final outputs that were calculated with the Core Counter calibration equation. The intermediate dry weight results were derived using moisture percentages determined for each core segment during laboratory analysis. A summary of the Core Counter bench scale test results is presented in Table 5 which displays the laboratory result and one sigma uncertainty along with the average and standard deviation of the four Core Counter readings.

Figures 4A, 4B, 5A, 5B and 6 contain graphical comparisons of the laboratory and average Core Counter results. In each of these figures, the laboratory total uranium result is plotted on the x-axis and the average Core Counter equivalent lab result is plotted on the y-axis. The solid diagonal line in each figure represents perfect agreement between lab and Core Counter. In Figure 4A all the data from both cores are plotted together. Figure 4B contains Core 1 and 2 data below 1,000 ppm, with the scale expanded to make the low range data more visible. Figures 5A and 5B are corresponding plots containing only Core 1 data. Figure 6 contains the graphical comparison for Core 2 data alone. In some instances there is good agreement between lab and Core Counter, while in other instances the agreement is not very good. The reasons for the lack of agreement will be discussed in the next section.

7.0 CALIBRATION VERIFICATION RESULTS

3239

The results of the bench scale test conducted on the two Plant 6 sample cores indicate a good correlation exists between a number of points along the entire range of values. However, there is also poor correlation at several points. A closer inspection shows that all but one of the poor correlations occurs for Core 1. Core 1 exhibits good correlation on Segments 2 and 3, which are considerably higher than the rest of the core as well as any segments on Core 2. When the correlation with the laboratory results is poor, it appears to be related to two factors: the level of activity, with the lowest having the worst correlation (Core 1, segment 6) and the proximity of the segment to a high activity segment (Core 1, Segment 4). Taken together, it appears that the high concentration segments are interfering with the counts of the low concentration segments. That is, since the gamma rays from the high concentration segments are not completely attenuated by the shield, the detector records some counts from gamma rays originating outside the shield during the process of counting the low activity segment in the Core Counter. While only a very small percentage of these gamma rays penetrate the shield, their numbers can be significant when a low activity source is being counted. This explanation is plausible because in all cases where the agreement between lab and Core Counter is poor, the Core Counter results are high. If these were random errors, some of the Core Counter results would be high while others would be low. In addition, most of the poor correlation comes from Core 1, which had two very high concentration segments of 39,700 ppm and 12,400 ppm.

A second point to note is that if the activity in one segment is concentrated near the interface between segments, then one segment could interfere with the counting of an adjacent segment, even without a large difference in the activities of the two segments. This appears to be the case for Segment 3 of Core 2. It is very possible that a large part of the activity in Segment 2 was clustered very near Segment 3. In this situation, the HPGe detector would record some counts from Segment 2 while Segment 3 was being counted in the Core Counter.

While interference from other segments could be a problem, it should be noted that the results are always conservative (i.e., biased high). It is also important to note that once an entire core is counted, it will be known if there are high concentration segments that could interfere with nearby segments and potentially affect WAC decisions. For example, after Core 2 is counted, it can be determined that Segments 2 through 7 are below the WAC level. Even if the results were elevated because of interference from other segments, the reported values are known to be conservative. If the results are close to a decision level and more accurate values are desired, the core can be physically cut into segments so that the individual segments can be recounted without interference from adjacent segments.

The moisture used for this verification test was determined in the course of the laboratory analyses of the separate core segments. In the field the moisture would be obtained using a Zeltex® infrared moisture meter after the core was cut open. If results were required prior to cutting, then a default moisture value of 20 percent dry basis moisture would be used. Applying the default moisture value to this verification test data would have resulted in values that were, on average, 3.7 percent higher than the values obtained using actual moisture measurements. The largest difference for a single Core Counter reading would have been 12.3 percent higher if the default moisture had been used. More importantly, the decisions discussed below that would be made with these data would not have changed had the default moisture been used.

3239

8.0 EVALUATION OF DECISIONS

During the bench scale testing, each segment was counted four separate times with the exception of Segment 7 of Core 2. Due to an error, this segment was counted only twice. Thus a total of 50 analyses on 13 segments from two different cores were performed. (See Tables 4A and 4B.) The individual results were examined to determine whether the proper decision would have been made regarding the WAC level. Of the 50 analyses, eight were performed on segments determined by lab gamma spectrometry analysis to be greater than 1,030 ppm, that is, above WAC. The Core Counter results for all eight counts were greater than WAC. Of the remaining 42 Core Counter results, seven others were above WAC. Four of these were from Segment 4 of Core 1 and three were from Segment 1 of Core 2. Overall, the bench scale test data indicate that, while the false positive error rate may become significant when total uranium concentrations reach the 800 to 1,000 ppm range, the Core Counter can reliably detect soil core segments that are truly above WAC. While a high false positive error rate in making WAC determinations is undesirable because it could result in unnecessary off-site disposal, the bench scale test data shows that the Core Counter is more likely to err on the side of conservatism. There is no direct evidence in the current data set that can be used to predict false negative error rates for WAC determinations because there are no segments just slightly in excess of WAC. The two above-WAC core segments in this data set are so far above WAC that one would expect these to be reliably categorized by the Core Counter. However, based on the Plant 6 bench scale data and the linear form of the calibration equation, the false negative error rate for WAC decisions is likely to be extremely low.

In addition to the WAC level, another important regulatory limit is the FRL. The ability of the Core Counter to distinguish above-FRL soil from below-FRL soil was also examined. Of the 50 Plant 6 bench scale test counts 18 were performed on core segments for which the laboratory result was less than 82 ppm total uranium on a dry weight basis. The core counter results for 14 of these 18 counts also turned out to be less than 82 ppm when the Core Counter calibration equation was applied to the EGAS output. The four counts that were below 82 ppm by laboratory analysis, but above 82 ppm according to the Core Counter, all occurred for Segment 6 of Core 1. As discussed in the previous section of this report, these elevated core counter results are probably due to interference counts coming from the other segments of Core 1. Because the true uranium content of Segment 6 is so low, the effect of the interference from other segments of Core 1 is greater, on a percentage basis, for this segment than for other Core 1 segments such as Segment 5. Twenty-four counts were performed on core segments with laboratory analysis results between FRL and WAC. None of the corresponding Core Counter results was

16

below FRL, and only seven were above WAC. The seven above-WAC Core Counter results occurred for Segment 1 of Core 2, as discussed above.

While the above analysis (i.e., 14 out of 18 below-FRL determinations and 17 out of 24 between-FRL-and-WAC determinations properly made by the Core Counter) indicates the possibility of extending Core Counter applications to making FRL determinations, the measurement uncertainties must also be considered when assessing the reliability of the results. It can be seen in Table 5 that the standard deviations of the replicate measurements are often as large as the means when the uranium concentration is below FRL. When assessing compliance of an *in situ* measurement with a regulatory limit, it is common practice to compare the result to a trigger level that has been set below the actual limit to provide a margin of safety that accounts for the measurement uncertainty. While the data look promising, further study of the FRL assessment issue is needed before the Core Counter can be recommended for this application. Counting core samples for a longer time interval is one approach that may make FRL determinations with the Core Counter feasible.

17

9.0 CONCLUSION

3239

When Core Counter raw measurements are moisture corrected and converted to laboratory equivalent dry weight results, they correlate closely to standard laboratory gamma spectrometry results for a wide range of uranium concentrations. This good correlation appears to break down if the segment being counted is adjacent to (or even just nearby) a segment with an elevated uranium concentration. The presence of a high concentration segment will, of course, be known once the entire core is counted. When this situation occurs, one solution could be to physically separate the core into its segments and then re-count them individually.

In general, the collection of core samples will be initiated for multiple purposes. Determination of the magnitude and extent of radiological contaminant migration is only one of the purposes. The normal practice is to split cores lengthwise to characterize the physical and chemical characteristics of the soil. It is only after trying to account for sloughing and soil compression or expansion that occurred during the collection of the cores that the soil in a core is separated into segments for further laboratory analysis. So, even when interferences between core segments is likely, it may not always be possible or desirable to cut a core into 6-inch segments for Core Counter analysis.

The Core Counter will be operated in accordance with RTIMP procedure EQT-35, "Soil Core Sample Counting System." A summary of the operating procedure follows. Routine instrument performance checks of the HPGe detectors used in the Core Counter system will be performed daily or prior to use, in accordance with approved RTIMP operations procedures. The Core Counter shield will be set up in a vehicle or structure near the sampling site. A dose rate meter, such as a micro-R meter, will be used to select a location with a reasonably low background. Accessibility to the sampling area and radiological control requirements, as well as background radiation levels, will influence where the counter is set up. Assembly and disassembly will be kept to a minimum so that operating conditions are kept as stable as possible. A "blank" core of the same diameter as the sample core, containing naturally occurring levels of uranium, will be counted each day that Core Counter analyses are performed. The blank result will be used to "blank correct" the raw sample results from the Core Counter. One of the standards described in Section 3.0 of this report will also be counted as a "control sample" (analogous to a laboratory control standard) before counting core samples. If the readout for the control sample is outside the range of 80 to 120 percent of the known value, the cause of the deviation will be investigated to determine if core samples may be counted. Typical sample count times will range from five to 15 minutes. Each 6-inch segment of each core will be counted unless directed otherwise by the PSP or project management. The samples will be "blank corrected" before a moisture correction is applied. Laboratory equivalent results will be calculated by applying the appropriate calibration equation to the blank-corrected and moisture-corrected *in situ* gamma spectrometry results. Remediation project engineers will be given results as soon as possible so that they can decide if additional core samples are required before demobilizing personnel and equipment. Depending on the diameter of the core sample, Core Counter results of 19.2 ppm and 30.6 ppm (moisture corrected) will be used as trigger levels for WAC decisions. The uranium concentration for soil at these trigger levels corresponds to laboratory equivalent results of 850 ppm. The trigger levels provide a margin of conservatism which accounts for measurement uncertainty. Results in excess of a trigger level will be considered to be above WAC.

A better knowledge of false positive and false negative error rates in WAC decisions would be beneficial to remediation projects. To that end, with the concurrence of the project involved, core samples having lab equivalent dry weight Core Counter results between 800 ppm and 1,200 ppm will be sent to a laboratory for total uranium analysis. Laboratory and Core Counter results will be compiled until a large enough data set is accumulated to better estimate false positive and false negative error rates for WAC decisions. (Project concurrence is needed because they may have other plans for the cores in question. Unless the Core counter and the laboratory analyze exactly the same 6-inch core segment, the comparative analyses will not be useful in determining WAC-decision error rates.)

The moisture content of these samples will also be measured as part of the laboratory analyses. These data will allow a more representative default moisture value for subsurface soil to be determined.

It is anticipated that the Core counter will be operated in the manner described above, under normal conditions. However, radiological conditions or other special circumstances associated with a given sampling location or project may warrant deviation from the normal operational mode in a number of possible ways. For example, the core counter could be assembled in a location remote from the sampling site, count times could be adjusted to meet special project requirements, or only selected cores would be counted in the Core Counter. It is expected that practices will evolve as field experience with the Core Counter provides lessons learned.

3239

10.0 RECOMMENDATION

The data in this report demonstrate that the Core Counter can be used for WAC determinations during predesign investigations and for control of soil excavation projects at the FEMP. The Core Counter will provide rapid and reliable determination of uranium concentrations at depth. The RTIMP recommends immediate approval for use of the Core Counter for making WAC decisions regarding subsurface soils. It would be another useful tool to aid in efficient, cost effective remediation of the FEMP site. Of course, information from the other real time gamma measurement tools can supplement Core Counter information during actual excavation. Because the Core Counter is currently calibrated for uranium only, it should not be used in areas where other isotopes are driving the excavation.

REFERENCES

3239

U.S. Department of Energy, 1999, "User Guidelines, Measurement Strategies, and Operational Factors for Deployment of In Situ Gamma Spectrometry at the Fernald Site," Draft, DOE, Fernald Environmental Management Project, Cincinnati, OH.

Table 1
Total Uranium Analyses of Dual Tube Calibration Standards

Laboratory Total U Results by Gamma Spectrometry							Core Counter Total U Results						
Result ppm DRY	Method Blank ppm DRY	Blank Corr Result ppm DRY	Avg.	Std. Dev.	Student's "t" Variate	95% Confidence Interval (2 sided)	Result ppm DRY	Method Blank ppm DRY	Blank Corr Result ppm DRY	Avg.	Std. Dev.	Student's "t" Variate	95% Confidence Interval (2 sided)
4.9	N/A	4.9					1.6	1.6	0				
5.1	N/A	5.1					0.87	0.87	0				
4.0	N/A	4.0	4.67	0.59	4.303	1.46	1.41	1.41	0				
							0.95	0.95	0	0	0	3.18245	0
290	N/A	290					7.65	1.6	6.0				
300	N/A	300					6.9	0.87	6.03				
290	N/A	290	293.3	5.77	4.303	14.34	7.58	1.41	6.17				
							7.26	0.95	6.31	6.13	0.14	3.18245	0.225
520	N/A	520					11.8	1.6	10.2				
520	N/A	520					12.7	0.87	11.83				
520	N/A	520	520	0	4.303	0	13.3	1.41	11.89				
							13.2	0.95	12.25	11.54	0.91	3.18245	1.452
610	N/A	610					14.4	1.6	12.8				
600	N/A	600					15.2	0.87	14.33				
590	N/A	590	600	10	4.303	24.84	16.1	1.41	14.69				
							15.6	0.95	14.65	14.12	0.89	3.18245	1.419
990	N/A	990					23.9	1.6	22.3				
1000	N/A	1000					24.7	0.87	23.83				
1000	N/A	1000	997	5.8	4.303	14.34	24.5	1.41	23.09				
							27.4	0.95	26.45	23.92	1.80	3.18245	2.862
1400	N/A	1400					27.5	1.6	25.9				
1300	N/A	1300					31.4	0.87	30.53				
1400	N/A	1400	1367	58	4.303	143.4	30.9	1.41	29.49				
							33.1	0.95	32.15	29.52	2.65	3.18245	4.211

Table 2
Total Uranium Analyses of Macro Core Tube Calibration Standards

Laboratory Total U Results by Gamma Spectrometry							Core Counter Total U Results						
Result ppm DRY	Method Blank ppm DRY	Blank Corr Result ppm DRY	Avg.	Std. Dev.	Student's "t" Variate	95% Confidence Interval (2 sided)	Result ppm DRY	Method Blank ppm DRY	Blank Corr Result ppm DRY	Avg.	Std. Dev.	Student's "t" Variate	95% Confidence Interval (2 sided)
4.5	N/A	4.5					1.51	1.51	0				
4.7	N/A	4.7					1.1	1.1	0				
4.4	N/A	4.4	4.53	0.15	4.303	0.38	1.57	1.57	0				
							0.71	0.71	0	0	0	3.18245	0
280	N/A	280					11.5	1.51	9.99				
290	N/A	290					11.4	1.1	10.3				
280	N/A	280	283	5.8	4.303	14.34	12.0	1.57	10.43				
							10.7	0.71	9.99	10.2	0.22	3.18245	0.354
460	N/A	460					17.5	1.51	15.99				
480	N/A	480					19.9	1.1	18.8				
480	N/A	480	473	11.6	4.303	28.7	18.9	1.57	17.33				
							13.2	0.71	12.49	16.2	2.70	3.18245	4.292
670	N/A	670					26.8	1.51	25.29				
650	N/A	650					27.4	1.1	26.3				
640	N/A	640	653	15.3	4.303	38	28.1	1.57	26.53				
							28.2	0.71	27.49	26.4	0.90	3.18245	1.438
1000	N/A	1000					32.4	1.51	30.89				
1000	N/A	1000					36.2	1.1	35.1				
1000	N/A	1000	1000	0	4.303	0	37.1	1.57	35.53				
							37.2	0.71	36.49	34.5	2.48	3.18245	3.943
1400	N/A	1400					54.0	1.51	52.49				
1400	N/A	1400					48.8	1.1	47.7				
1400	N/A	1400	1400	0	4.303	0	51.8	1.57	50.23				
							51.0	0.71	50.29	50.2	1.96	3.18245	3.116

23

Table 3
Dual Tube and Macro Core Linear Regression Statistics

	Dual Tube	Macro Core
R Square	0.99276	0.99305
Standard Error of Regression	46.5103	46.9100
Slope	44.351	27.835
Slope 95% Confidence Interval	±5.259	±2.155
Intercept	0.3408	-1.7284
Intercept 95% Confidence Interval	±91.424	±91.161

Table 4A
Plant 6 Bench Scale Test Data - Core 1

Core No.	Segment No.	Core Counter Raw Output Total U ppm WET	Lab Wet Base % Moisture	Moisture Corrected Core Cntr Output Total U ppm DRY	Core Counter Equivalent Lab Result Total U ppm DRY	Lab Total U ppm DRY	1 Sigma Lab Uncertainty ppm DRY
1	1	3.7	6.4	3.9	174		
	1	6.0	6.4	6.4	283		
	1	4.6	6.4	4.9	217		
	1	5.5	6.4	5.8	259	144	2
1	2	217	7.2	234	10400		
	2	284	7.2	306	13600		
	2	289	7.2	311	13800		
	2	286	7.2	308	13700	12400	11
1	3	927	8.9	1017	45100		
	3	811	8.9	890	39500		
	3	821	8.9	901	40000		
	3	829	8.9	910	40400	39700	34
1	4	34.6	17.3	41.8	1850		
	4	31.1	17.3	37.6	1670		
	4	30.1	17.3	36.4	1620		
	4	29.3	17.3	35.4	1570	1000	43
1	5	12.0	18.2	14.6	649		
	5	9.1	18.2	11.1	493		
	5	8.5	18.2	10.4	463		
	5	9.0	18.2	11.0	488	325	3
1	6	10.4	13.2	11.9	530		
	6	6.2	13.2	7.1	315		
	6	8.1	13.2	9.3	412		
	6	8.1	13.2	9.3	414	60	1.4

25

Table 4B
Plant 6 Bench Scale Test Data - Core 2

Core No.	Segment No.	Core Counter Raw Output Total U ppm WET	Lab Wet Base % Moisture	Moisture Corrected Core Cntr Output Total U ppm DRY	Core Counter Equivalent Lab Result Total U ppm DRY	Lab Total U ppm DRY	1 Sigma Lab Uncertainty ppm DRY
2	1	24.8	10.4	27.6	1230		
	1	14.1	10.4	15.7	698		
	1	21.8	10.4	24.4	1080		
	1	21.9	10.4	24.4	1080	977	4
2	2	11.4	10.5	12.7	563		
	2	7.1	10.5	8.0	354		
	2	9.7	10.5	10.9	483		
	2	10.0	10.5	11.2	496	472	4
2	3	7.47	13.4	8.6	383		
	3	3.55	13.4	4.1	182		
	3	5.97	13.4	6.9	306		
	3	5.58	13.4	6.4	286	101	2
2	4	0.55	18.7	0.68	30.3		
	4	0	18.7	0	0.34		
	4	0.13	18.7	0.16	7.4		
	4	-0.18	18.7	-0.22	-9.5	8.8	1.2
2	5	1.32	18.3	1.62	72.0		
	5	-1.24	18.3	-1.52	-67.0		
	5	0.060	18.3	0.073	3.6		
	5	0.12	18.3	0.15	6.9	7.2	1.1
2	6	1.32	18.9	1.63	72.5		
	6	1.20	18.9	1.48	66.0		
	6	0.23	18.9	0.28	12.9		
	6	-0.20	18.9	-0.25	-10.6	11.9	1.5
2	7	0.020	17.3	0.024	1.4		
	7	-0.16	17.3	-0.19	-8.2	13.3	1.1

26

3239

Table 5
Plant 6 Bench Scale Test – Summary

Core No.	Segment No.	Lab Total U ppm DRY	1 Sigma Lab Uncertainty ppm DRY	Ave Core Counter Equivalent Lab Result ppm DRY	1 Sigma Core Counter Std Dev ppm DRY
1	1	144	2	233	48
1	2	12400	11	12800	1700
1	3	39700	34	41200	2600
1	4	1000	43	1680	120
1	5	325	3	523	85
1	6	60	1.4	418	88
2	1	977	4	1020	230
2	2	472	4	474	88
2	3	101	2	289	83
2	4	8.79	1.17	7.2	17
2	5	7.24	1.08	3.9	57
2	6	11.9	1.5	35.2	41
2	7	13.3	1.1	-3.4	6.8

Figure 1: Core Counter (Top View)

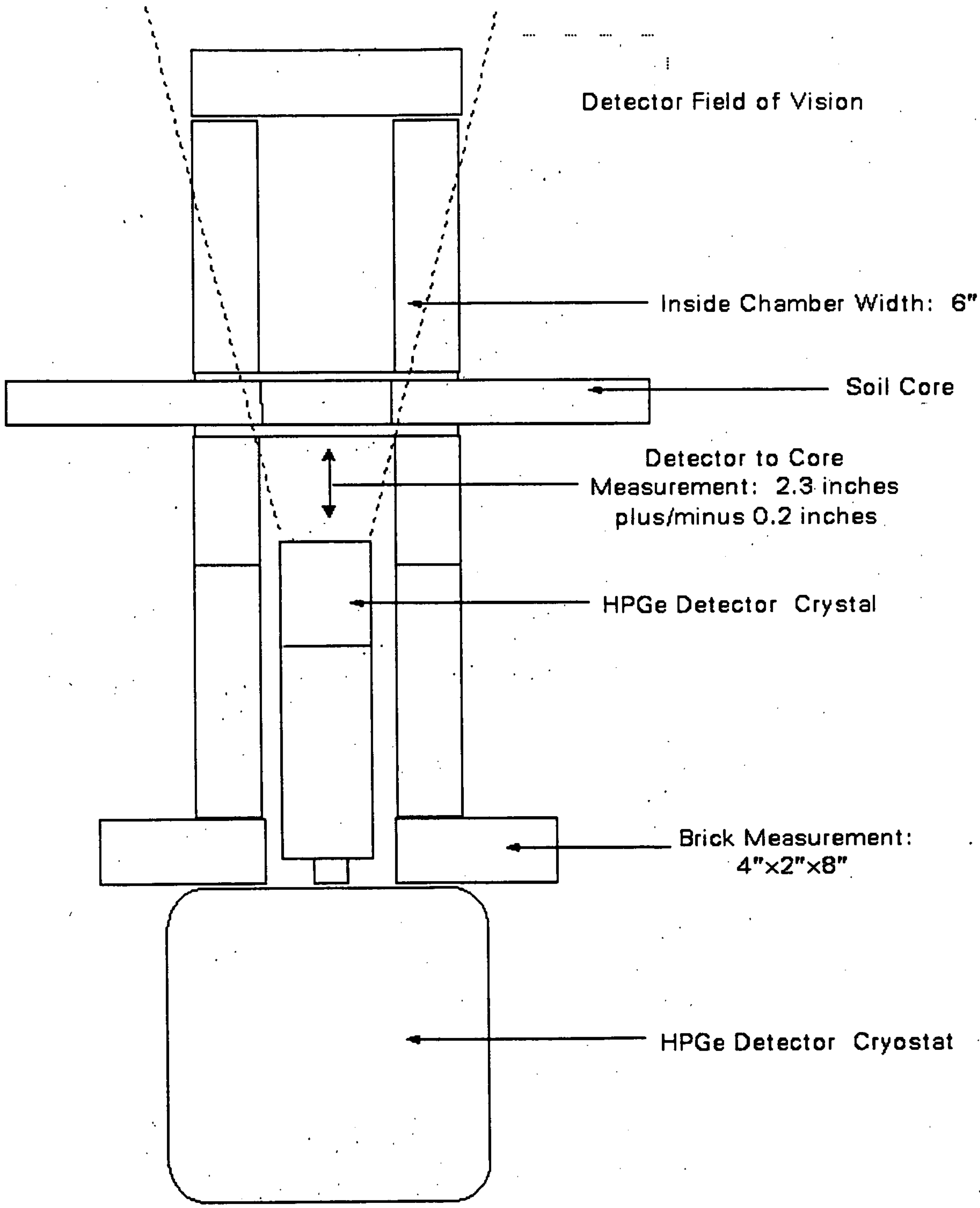
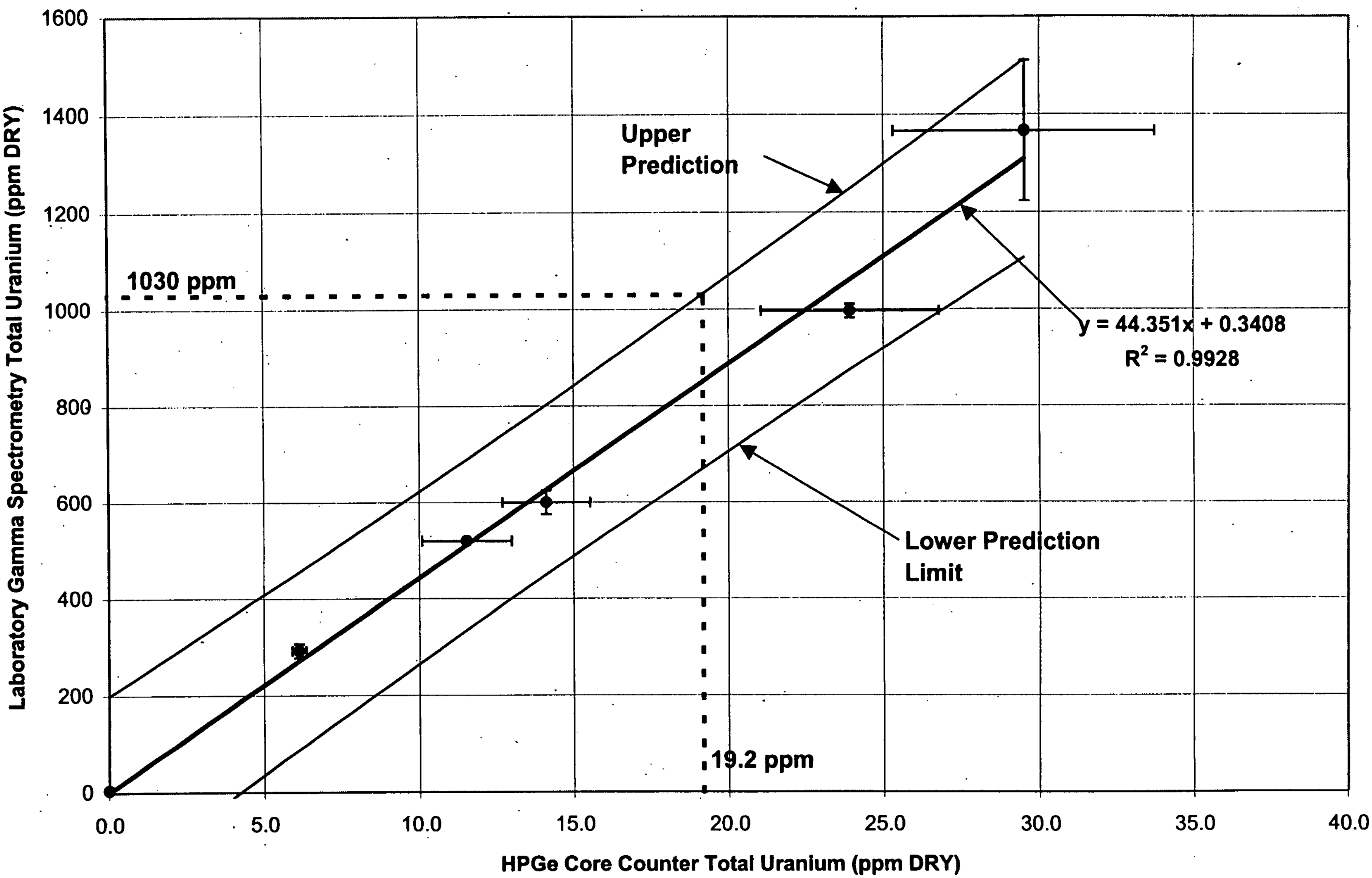
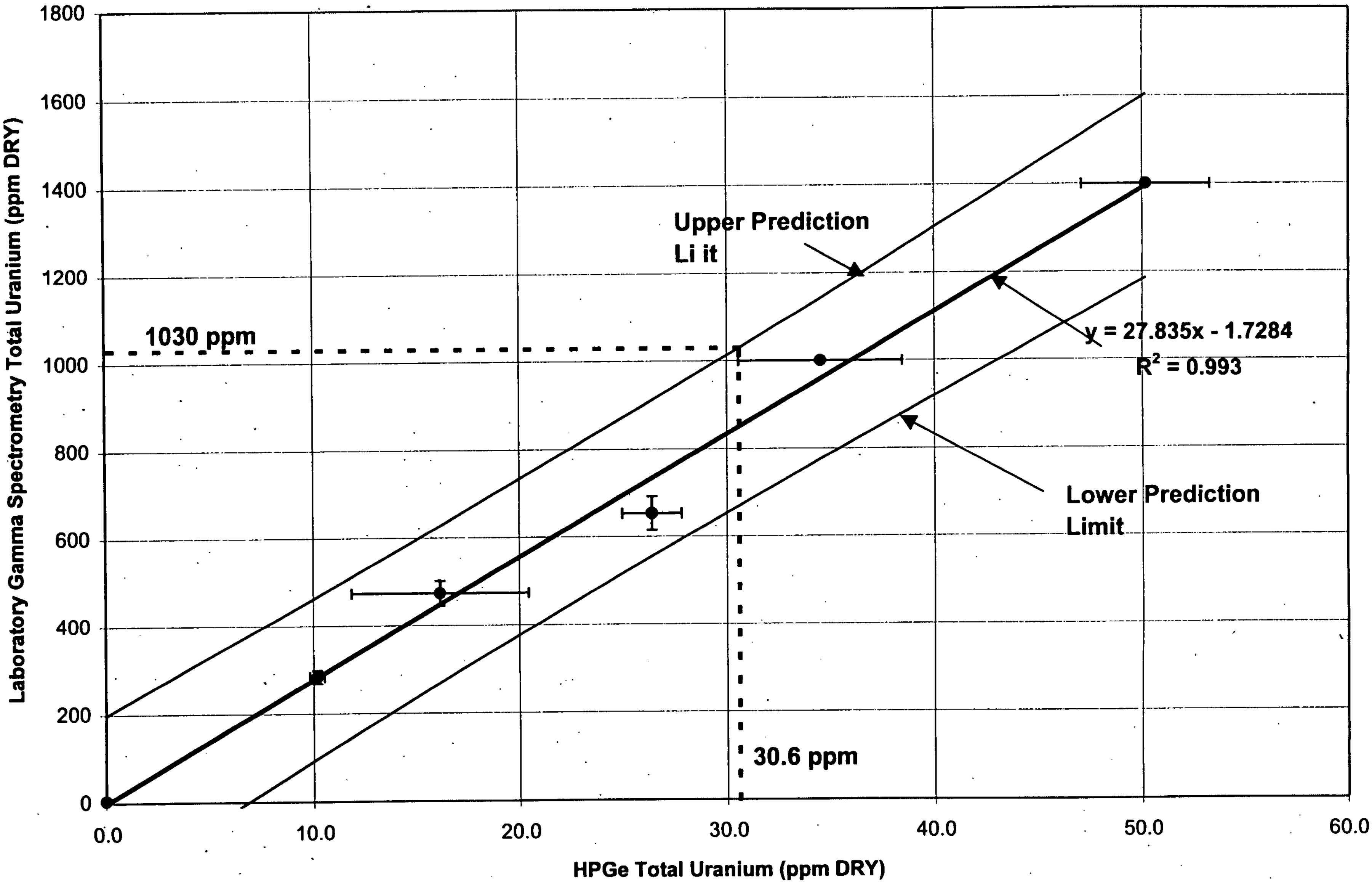


Figure 2: CORE COUNTER CALIBRATION CURVE
Dual Tube Cores vs Laboratory Gamma Spectrometry (15 Minute Count Time)



29

Figure 3: CORE COUNTER CALIBRATION CURVE
Macro Tube Cores vs Laboratory Gamma Spectrometry (15 Minute Count Time)



3239

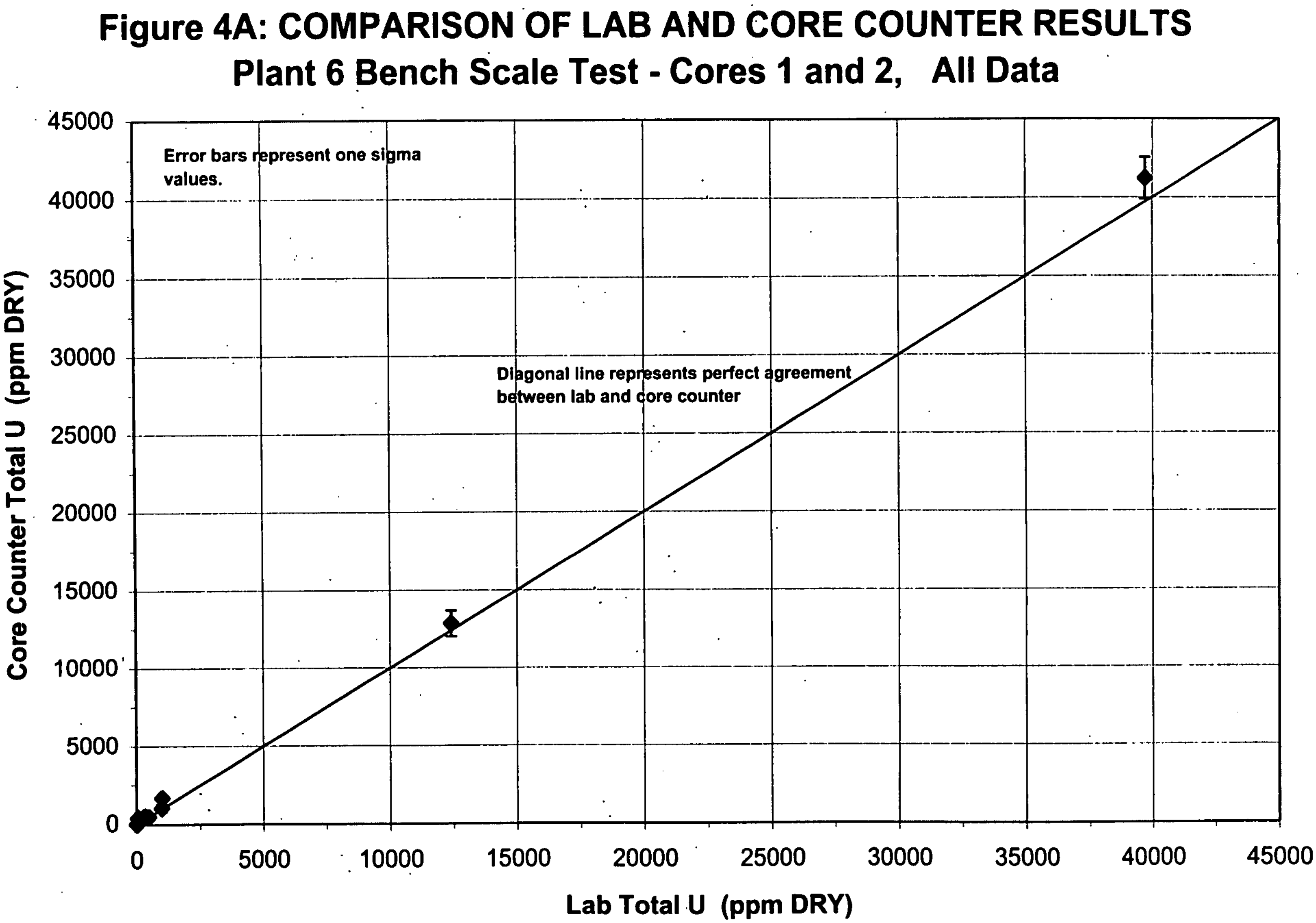
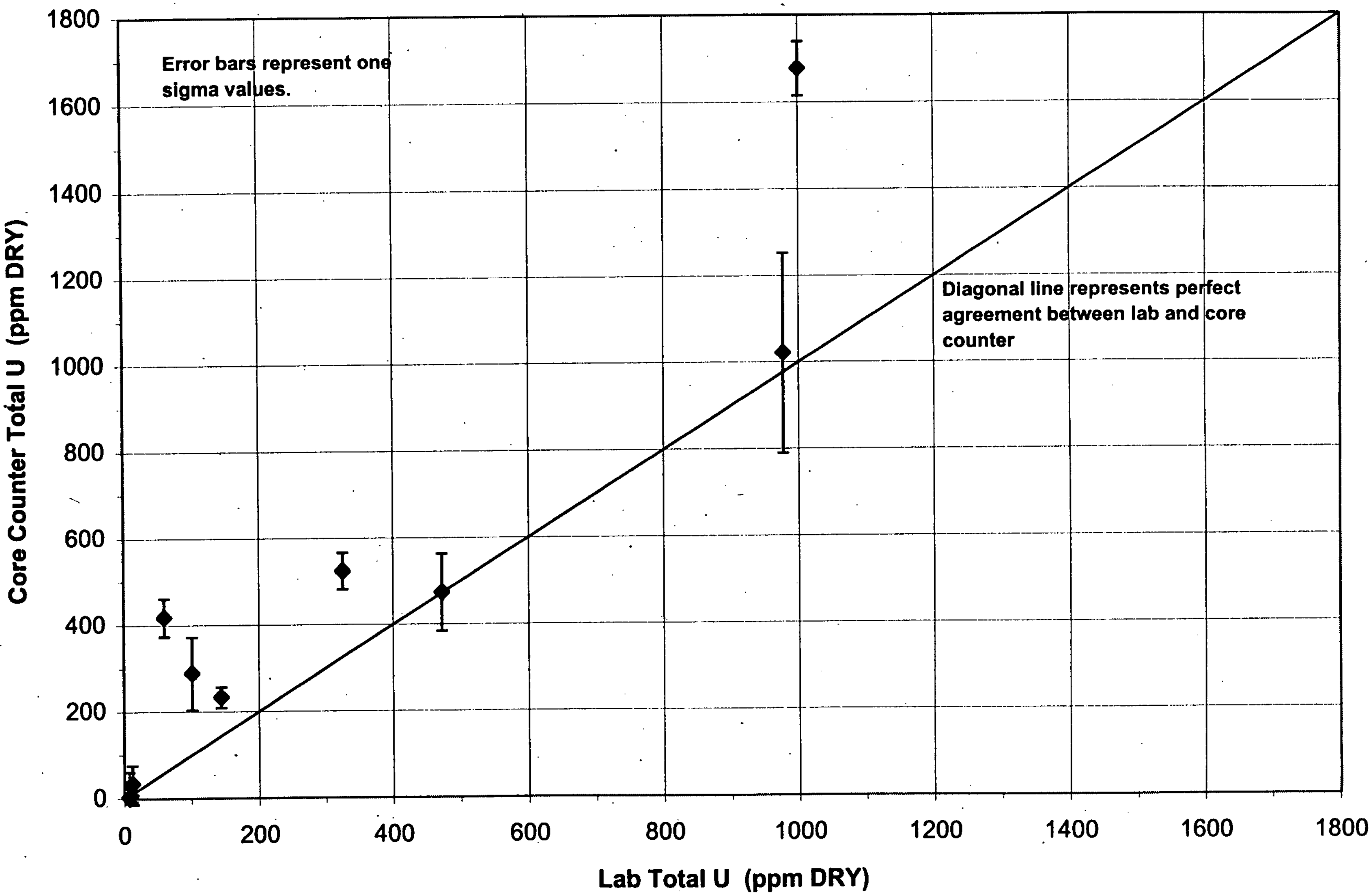


Figure 4A: COMPARISON OF LAB AND CORE COUNTER RESULTS
Plant 6 Bench Scale Test - Cores 1 and 2, All Data
Error bars represent one sigma values.
Diagonal line represents perfect agreement between lab and core counter
Core Counter Total U (ppm DRY)
Lab Total U (ppm DRY)
0
5000
10000
15000
20000
25000
30000
35000
40000
45000

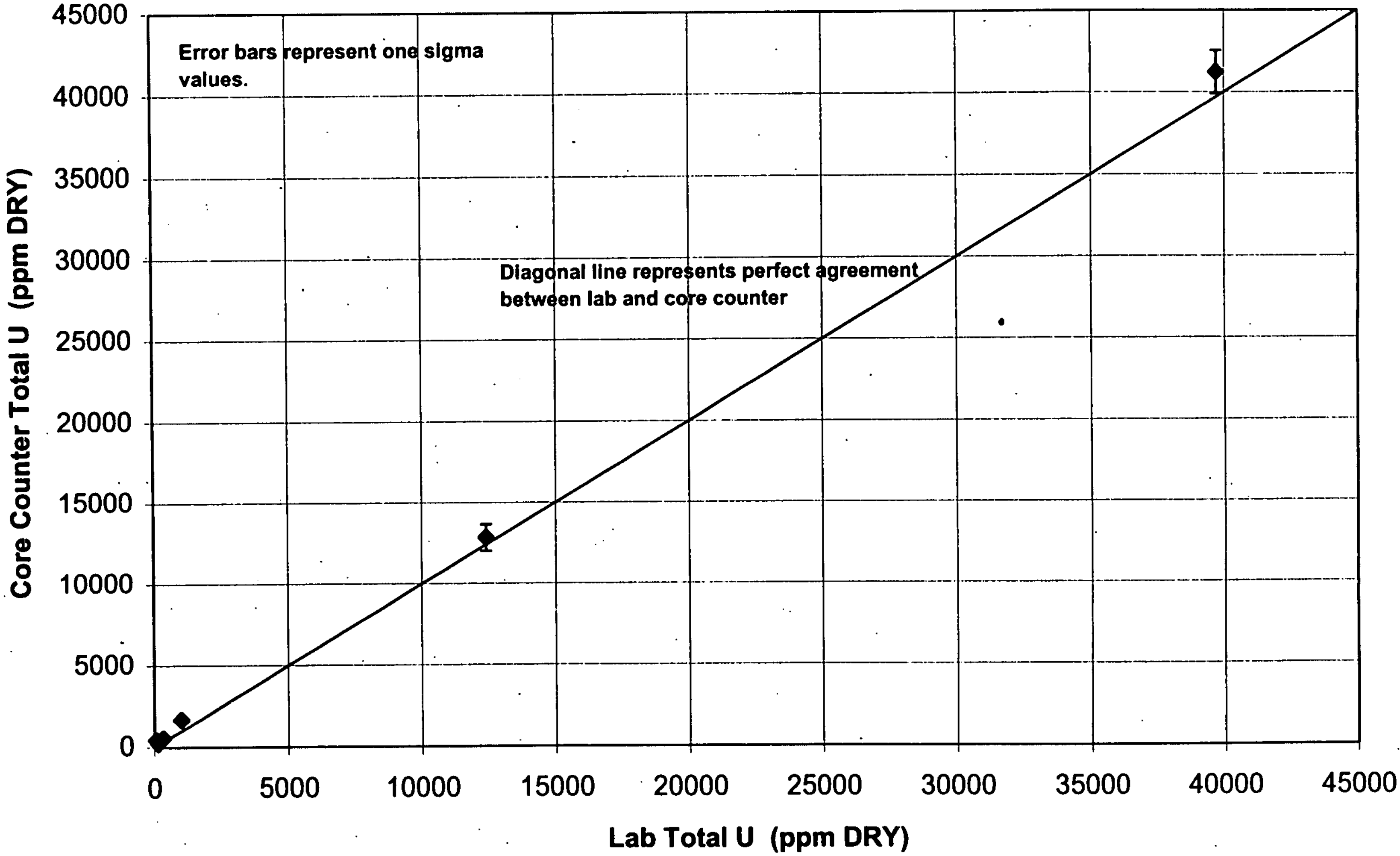
31

Figure 4B: COMPARISON OF LAB AND CORE COUNTER RESULTS
Plant 6 Bench Scale Test - Cores 1 and 2, 0 to 1000 ppm



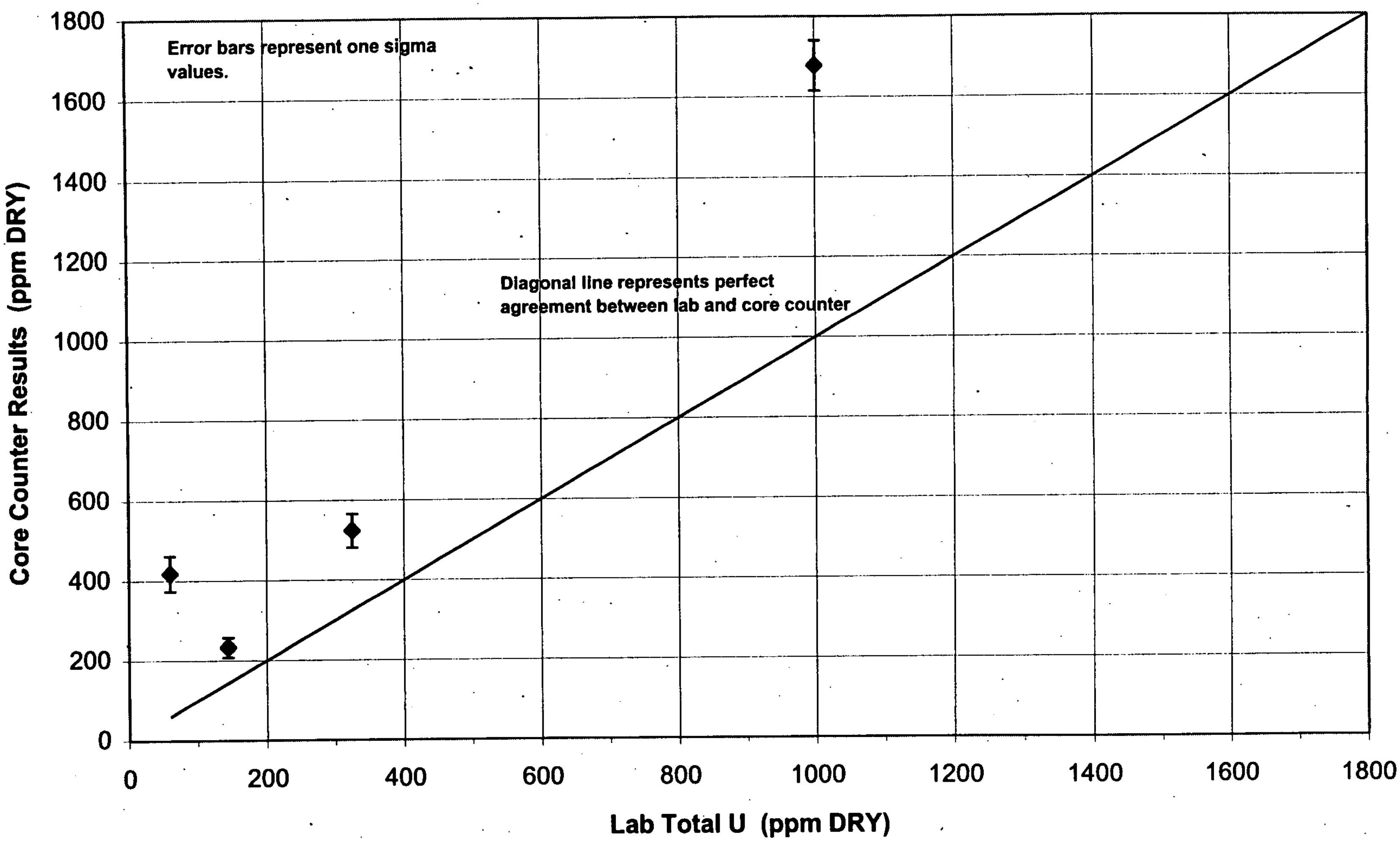
3239

Figure 5A: COMPARISON OF LAB AND CORE COUNTER RESULTS
Plant 6 Bench Scale Test - Core No. 1, All Data



33

Figure 5B: COMPARISON OF LAB AND CORE COUNTER RESULTS
Plant 6 Bench Scale Test - Core No. 1, 0 to 1000 ppm



3239

Figure 6: COMPARISON OF LAB AND CORE COUNTER RESULTS
Plant 6 Bench Scale Test - Core No. 2